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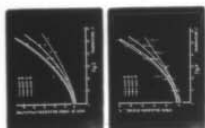
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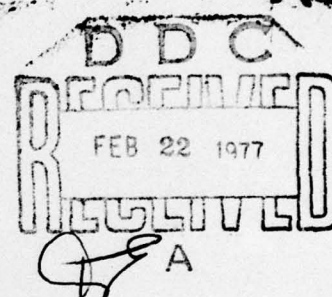
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STRESS RELAXATION OF DENTAL AMALGAM ALLOYS

Eugene F. Huget<sup>\*</sup>  
Laszlo B. de Simon<sup>\*\*</sup>  
Robert S. Hertert<sup>\*\*\*</sup>

Division of Dental Materials  
U.S. Army Institute of Dental Research  
Washington, D.C. 20012



Commerical materials and equipment are identified in this report to specify the experimental procedure. Such identification does not imply official recommendation or endorsement or that the equipment and materials are necessarily the best available for the purpose.

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- \* Lieutenant Colonel, Dental Corps, U.S. Army, Chief, Division of Dental Materials, U.S. Army Institute of Dental Research.
  - \*\* Physical Science Technician, Division of Dental Materials, U.S. Army Institute of Dental Research.
  - \*\*\* Captain, Medical Service Corps, U.S. Army, Division of Dental Materials, U.S. Army Institute of Dental Research.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Silver-amalgam is the most commonly used dental material for the restora- tion of carious and damaged posterior teeth. The popularity of these unique alloys is based primarily on their ease of manipulation and high strength characteristics. Unfortunately, however, the longevity of an amalgam restora- tion seldom exceeds ten years. Premature clinical failure appears to result from breakdown of the restorative material at the "tooth-filling" interface. The Division of Dental Materials, U.S. Army Institute of Dental Research, has conducted detailed studies of the static and dynamic properties of dental		

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→ amalgam alloys. We have found that stress relaxation behavior of these material correlates well with observed clinical longevity. Alloys that exhibit excessive stress relaxation over the range of temperatures encountered in the oral cavity fail relatively early in clinical service. Conversely, alloys that show little stress relief in laboratory testing yield consistently better and longer lasting serviceability.

Dissemination of precise and accurate data that characterize the relaxation behavior of dental amalgam alloys available for use within the military services will encourage reformulation of inferior products by responsible commercial sources. Delivery of unsatisfactory alloys to the Federal Health Services will thereby be precluded.

→ Short term stress relaxation of four amalgam alloys was studied. Test materials included three L. D. Caulk products (20th Century Micro Cut, 20th Century Fine Cut and Spherical Alloy) and Johnson & Johnson's Dispersalloy. Specimens were 24 hr-old 4 X 8 mm cylinders. The specimens were compressed and held at constant strain on development of a stress ( $S_0$ ) of 4,000 psi. Subsequent stress relaxation ( $D_t$ ) was recorded for 60 sec. Data obtained at eight nominal temperatures between 0 and 55C. were

Over the experimental temperature range, fractional stress losses at 60 sec

$(\frac{D_t}{S_0} \backslash 60)$  for specimens made from lathe cut alloys increased from 10 to 58%.

Spherical Alloy and Dispersalloy exhibited fractional stress losses  $(\frac{D_t}{S_0} \backslash 60)$

ranging from 9 to 47% and 9 to 31%, respectively. Fractional stress losses were linear when plotted against log time. Stress relaxation for all four alloys increased exponentially with time in accordance with the expression

$D_t / S_0 = \alpha e^{\beta t (^\circ K)}$ . Coefficients for the alloys were: 20th Century Micro Cut,  $\alpha = 2.52 \times 10^{-5}$  and  $\beta = 3.08 \times 10^{-2}$ ; 20th Century Fine Cut,  $\alpha = 1.22 \times 10^{-5}$  and  $\beta = 3.30 \times 10^{-2}$ ; Spherical Alloy,  $\alpha = 1.65 \times 10^{-5}$  and  $\beta = 3.14 \times 10^{-2}$ ; Dispersalloy,  $\alpha = 1.06 \times 10^{-4}$  and  $\beta = 2.49 \times 10^{-2}$ . Correlations between coefficients ranged from .976 for Dispersalloy to .995 for 20th Century Fine Cut.

→ It would appear that particle morphology and alloy composition affect stress relaxation behavior of dental amalgam. Stress decay patterns enhance significantly the mechanical characterization of amalgam alloys.

The dental amalgam restoration exhibits responses to applied stresses which contain both viscous and elastic components. The so-called viscoelastic behavior of hardened silver amalgam is time dependent. Oglesby et al<sup>1</sup> have shown that three patterns of strain typify the behavior of amalgam alloy: (1) Instantaneous elastic strain; (2) retarded elastic strain (transient creep) and (3) viscous strain (steady state creep). In addition to creep, a progressive increase in deformation under constant load, materials that behave viscoelastically may also show other time-dependent characteristics. One such characteristic is stress relaxation, a gradual decrease in stress under a constant strain. Stress relaxation results from the rearrangement of structural units. Alteration of structural configuration leads to the development of a new state of equilibrium.

Data obtained from stress relaxation studies have been of value in the selection of a number of industrial materials for load bearing applications.<sup>2</sup> Since amalgam restorations are repeatedly subjected to transient pressures, it would appear that similar studies would have relevance in the mechanical characterization of a variety of available alloys. The present investigation was conducted to study the stress-relaxation behavior of four amalgam alloys over the range of temperatures encountered in the oral cavity.

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## Materials and Methods

Test materials included two conventional lathe-cut alloys ( $A^*$  and  $B^+$ ), a spherical product ( $C^{\S}$ ) and a high-copper, dispersed phase alloy ( $D^{\Omega}$ ). Amalgam mixtures were made as directed by manufacturers' instructions regarding mercury-alloy portions and trituration times. Trituration was accomplished with the use of a mechanical device.<sup>II</sup> The amalgamated materials were packed into 4 mm X 8 mm steel molds by the all-mechanical procedure prescribed by American Dental Association Specification No. 1.<sup>3</sup> The condensed specimens were stored for 24 hours at 37C and 100 percent relative humidity. The ends of the 24 hr-old test pieces were surfaced plane and at right angles to their axes. The trimmed cylinders were conditioned for two hours in a constant temperature water bath. Then, the specimens were tested within the water bath over a 0 to 55C temperature range by the following procedure. Each specimen was compressed axially on a constant strain-rate testing machine<sup>¶</sup> at a crosshead speed of 0.02 inch/min. When a stress ( $S_0$ ) of  $28 \text{ MN/m}^2$  was reached, descent of the crosshead was stopped. Subsequent relaxation of the loaded specimens allowed a measurable

- 
- \* 20th Century Micro Cut, L. D. Caulk Co., Milford, DE 19963.
  - + 20th Century Fine Cut, L. D. Caulk Co., Milford, DE 19963.
  - § Caulk Spherical, L. D. Caulk Co., Milford, DE 19963.
  - Ω Dispersalloy, Johnson and Johnson, East Windsor, NJ 08520.
  - II Wig-L-Bug, Crescent Dental Mfg. Co., Lyons, IL 60534.
  - ¶ Instron Universal Testing Machine, Instron Corp., Canton, MA 02021.

stress loss ( $D_t$ ) with no change in strain. Stress was measured at 6-second interval over a 60-second period. Eight test temperatures with nominal values of 0, 10, 20, 30, 38, 42, 48, and 55C were used. Six specimens of each of the four alloys were tested at each temperature. To compensate for inherent relaxation of the testing machine, a 4 mm X 8 mm stainless-steel specimen was subjected to the compression procedure before and after the testing of three amalgam cylinders. The resulting system-relaxation pattern was used in adjusting the experimental data. A schematic of the compression-relaxation sequence and relevant terminology are given in Figure 1.

#### Results

Over the experimental temperature range, relaxation curves for the four alloys were similar in shape to the curve shown in Figure 1. Also, fractional stress-loss ( $D_t/S_0$ ) curves were similar to one another in shape but differed in rate as temperature varied. Typical fractional stress-loss ( $D_t/S_0$ ) curves, with temperature as a variable, are shown in Figure 2. Fractional stress-loss patterns did not vary linearly with time (Fig 2, A). However, the curves became linear when plotted against log time (Fig 2, B). Relaxation rates with respect to log time were delineated by the slopes of these lines. Relative relaxation rates for the amalgam alloys are presented in Figure 3. Stress-relaxation rates for all test materials varied exponentially with temperature.

Curves for total stress loss at 60 seconds ( $D_t/S_o/60$ ) are given in Figure 4. Over the 0 to 55C temperature range, stress losses at 60 seconds for the lathe-cut alloys (A and B) increased from about 10 percent to 58 percent. The spherical material (C) and the dispersed phase product (D) showed stress losses ( $D_t/S_o/60$ ) that ranged from 9 percent to 47 percent and from 9 percent to 31 percent, respectively. Stress relaxation patterns of all four alloys conformed to the expression  $D_t/S_o = \alpha e^{\beta T(K)}$ . Coefficients which describe the exponential increase in stress-loss over the 60-second test period were obtained by regression analysis of values for  $\ln(D_t/S_o/60)$  versus temperature. Validity of the analysis was reflected by  $r$  values that ranged from 0.976 for alloy D to 0.995 for alloy B. Coefficients for the alloys were: Alloy A,  $\alpha = 2.52 \times 10^{-5}$  and  $\beta = 3.08 \times 10^{-2}$ ; alloy B,  $\alpha = 1.22 \times 10^{-5}$  and  $\beta = 3.30 \times 10^{-2}$ ; alloy C,  $\alpha = 1.65 \times 10^{-5}$  and  $\beta = 3.14 \times 10^{-2}$ ; alloy D,  $\alpha = 1.06 \times 10^{-4}$  and  $\beta = 2.49 \times 10^{-2}$ .

#### Discussion

The viscoelastic behavior of many materials is dependent upon both long-duration and short-duration mechanisms. Some rheological data can be obtained only through relatively long (minutes to hours) periods of testing. Static creep values (percent change in length) based on one- and four-hour measurements have been reported by Osborne, et al.<sup>4</sup> Also, stress relaxation behavior of dental amalgam has been observed over a duration of 100 minutes by Paddon and Wilson.<sup>5</sup>



The test used in this study, however, was limited to 60 seconds because masticatory forces are brief and the short-term responses of stress bearing restorative materials merit consideration.

The coincidence of the onset of relaxation with maximum applied stress (Fig 1) reflects an instantaneous loss of strain energy. This, in turn, would suggest that strain-recovery of dental amalgam after deformation by external forces of short duration and of relatively low magnitude would not be complete. It would appear, therefore, that stress relaxation is a precursor of steady state (nonrecoverable) creep.

Although creep has been correlated with the rate at which marginal deterioration of an amalgam restoration occurs, its mode of influence has not been elucidated. Stress relaxation which follows deformation induced by transient masticatory forces or thermal expansion and contraction may provide the means by which clinical observable opening of the tooth-amalgam margin occurs.

#### Summary

Stress-relaxation behavior of four amalgam alloys was studied. Over the experimental temperature range of 0 to 55C, conventional lathe-cut alloys exhibited the greatest increase in fractional stress loss, whereas a material that contained a silver-copper dispersant showed the least.

Stress-decay patterns significantly enhance the mechanical characterization of dental amalgam alloys.

### Legends for Figures

Figure 1. Stress relaxation curve. Time  $t_0$  is onset of relaxation phase, coincident with maximum stress,  $S_0$ . Stress at any time  $t$  is  $S_t$ . Shaded area represents relaxation of testing machine.  $D_t$  is numerical difference between  $S_0$  and  $S_t$  after subtraction of testing machine relaxation.

Figure 2. Typical fractional stress-loss curves with temperature as a parameter. (A)  $D_t/S_0$  versus time; and (B)  $D_t/S_0$  versus  $\ln(\text{time} + 1)$ .

Figure 3. Relative relaxation rates of dental amalgam alloys. Curves are best-fit approximations.

Figure 4. Stress losses of dental amalgam alloys at 60 seconds.

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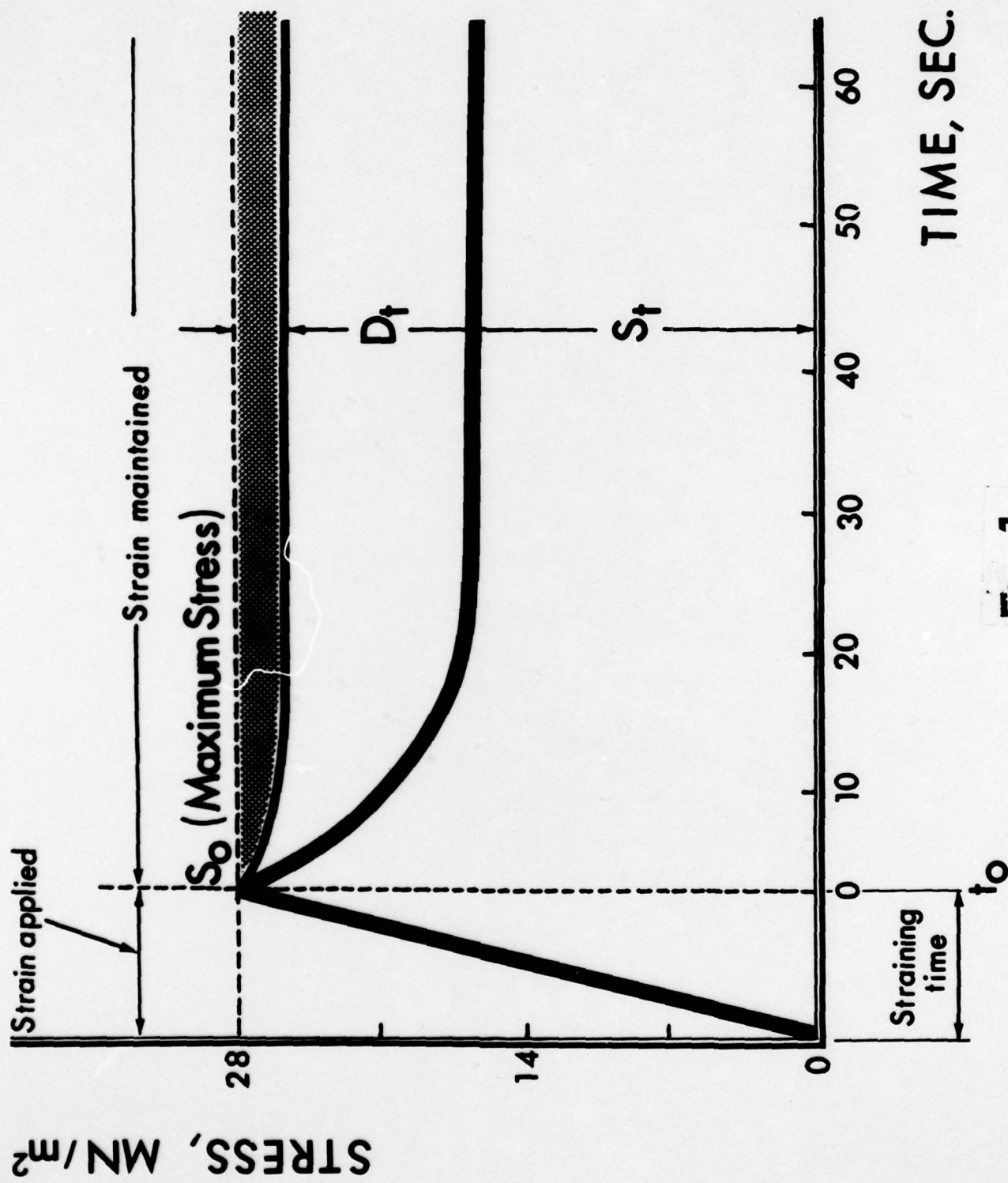


Fig.1

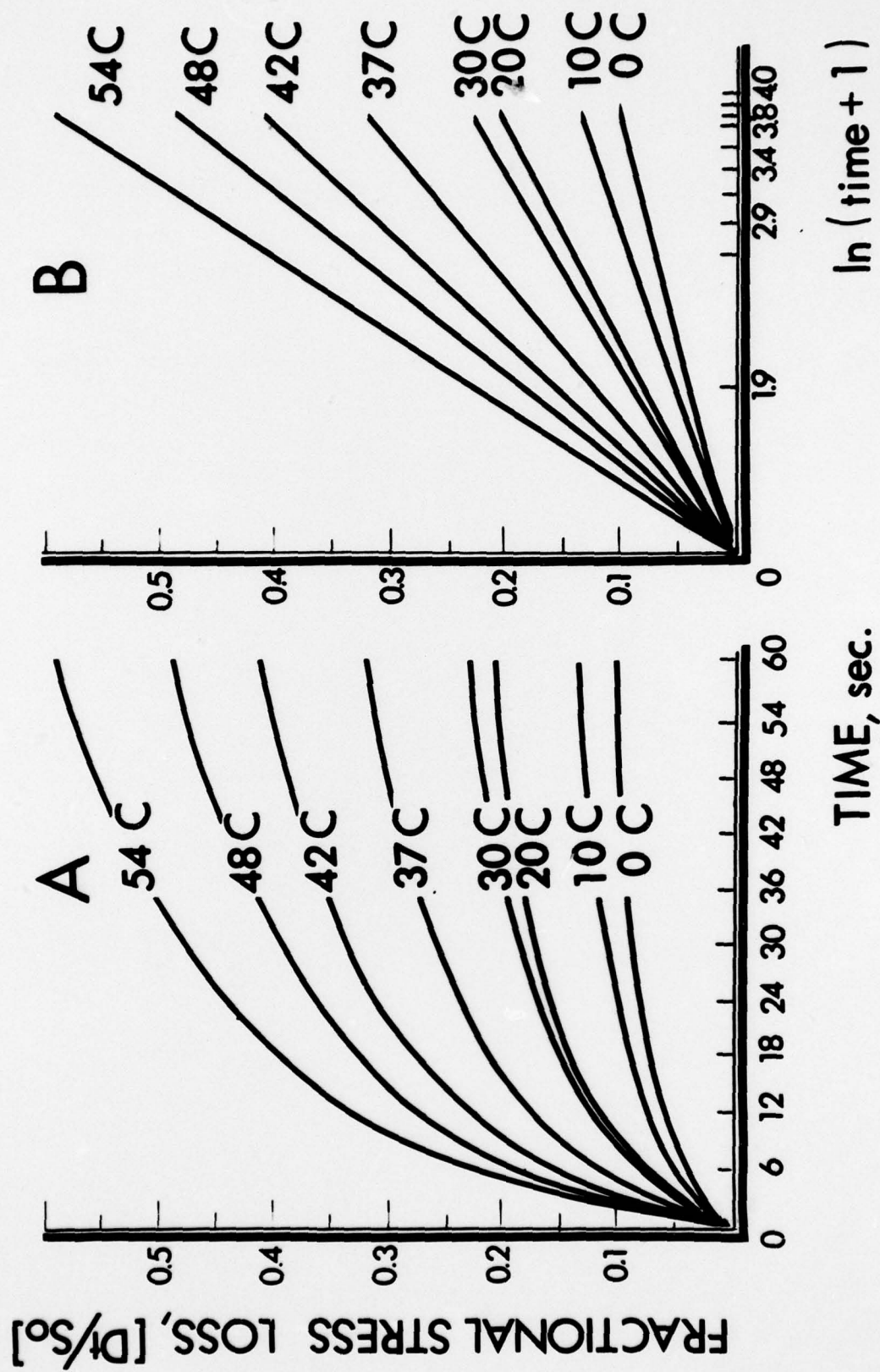


Fig.2

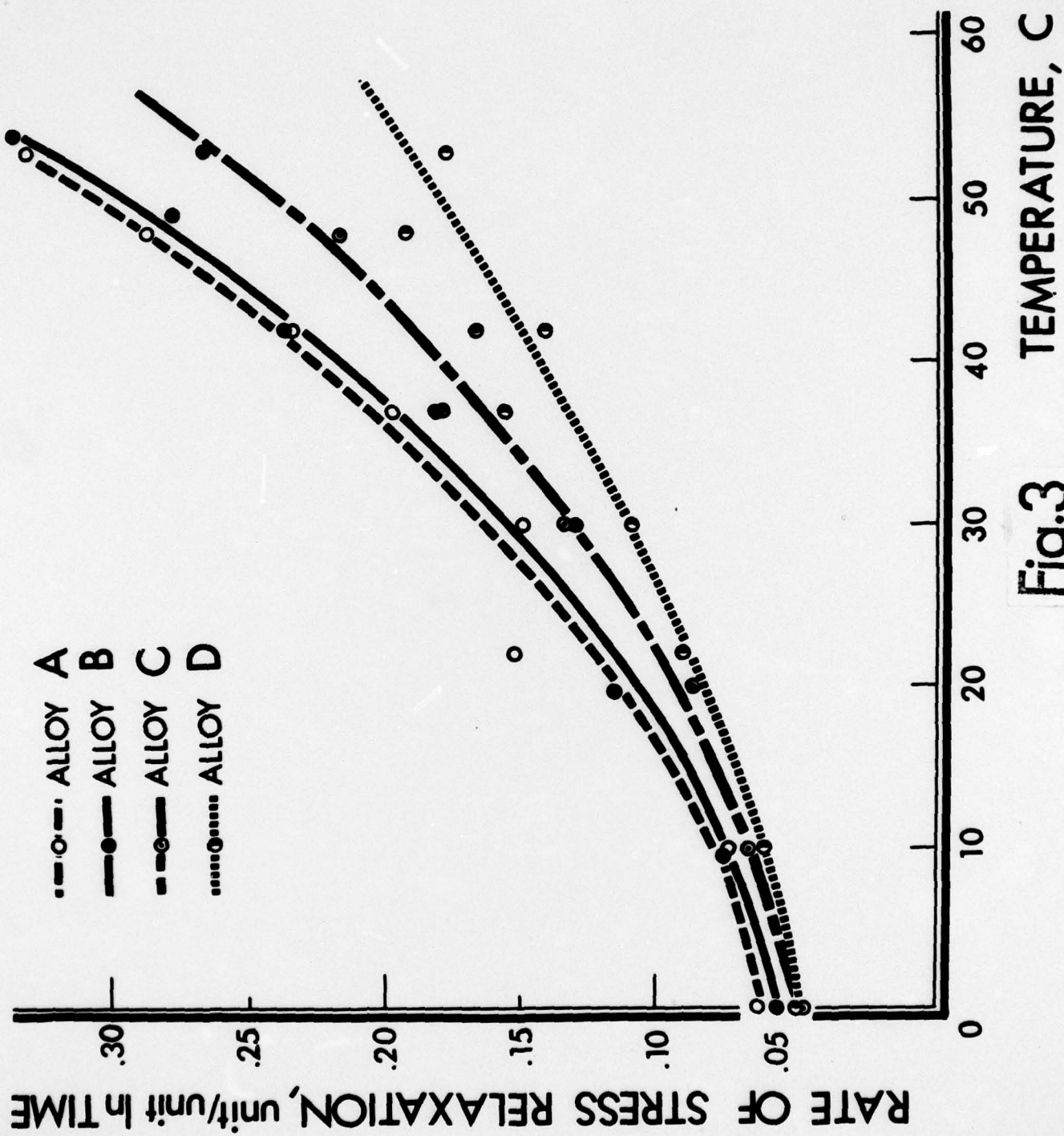


Fig.3



